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A new approach to correct for absorbing aerosols in OMI UV

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[1] Several validation studies of surface UV irradiance based on the Ozone Monitoring Instrument (OMI) satellite data have shown a high correlation with ground-based measurements but a positive bias in many locations. The main part of the bias can be attributed to the boundary layer aerosol absorption that is not accounted for in the current satellite UV algorithms. To correct for this shortfall, a post-correction procedure was applied, based on global climatological fields of aerosol absorption optical depth. These fields were obtained by using global aerosol optical depth and aerosol single scattering albedo data assembled by combining global aerosol model data and ground-based aerosol measurements from AERONET. The resulting improvements in the satellite-based surface UV irradiance were evaluated by comparing satellite and ground-based spectral irradiances at various European UV monitoring sites. The results generally showed a significantly reduced bias by 5–20%, a lower variability, and an unchanged, high correlation coefficient. **Citation:** Arola, A., et al. (2009), A new approach to correct for absorbing aerosols in OMI UV, *Geophys. Res. Lett.*, *36*, L22805, doi:10.1029/2009GL041137.

1. Introduction

[2] Surface UV estimates based on the Ozone Monitoring Instrument (OMI) satellite data continue the long-term TOMS UV record. OMI is a Dutch-Finnish instrument onboard NASA's EOS-Aura satellite. The OMI UV algorithm [*Tanskanen et al.*, 2007] is based on the experience with TOMS [*Eck et al.*, 1995; *Krotkov et al.*, 1998, 2001]. It consists of a calculation for the clear sky case, with corrections for clouds (or non-absorbing aerosols). Several validation studies of both TOMS and OMI-UV data have shown a positive bias in many locations, with the satellite-derived UV being higher than ground-based UV [e.g., *Chubarova et al.*, 2002; *Arola et al.*, 2005; *Meloni et al.*, 2005; *Buchard et al.*, 2008; *Ialongo et al.*, 2008; *Kazantzidis et al.*, 2006; *Kazadzis et al.*, 2009]. It has been suggested that the main part of the bias can be attributed to the boundary layer aerosol absorption that is not accounted for in the current satellite UV algorithms.

[3] The main parameters required for a correction of absorbing aerosols are the aerosol optical depth, τ_{aer} and the aerosol single scattering albedo, ω. These are needed to produce the global fields for aerosol absorption optical depth, τ_{abs} used in the correction proposed by *Arola et al.* [2005] and *Krotkov et al.* [2005]. The application of this type of correction has been hindered by the lack of proper global data set of aerosol absorption. Even if the satellite-derived τ_{abs} was of better accuracy, the data would be only available for clear-sky conditions, therefore in many locations only a limited temporal coverage can be reached. An alternative approach is to use a climatology of τ_{abs} in an attempt to achieve better accuracy in time-averaged satellite-derived surface UV. In this paper we present an aerosol correction for the OMI UV data, exploiting the newly developed aerosol climatology of *Kinne* [2009]. We also evaluate the improvements in the OMI UV that can be achieved with this correction, by comparing spectral OMI UV products with synchronous ground-based measurements from various European UV monitoring sites that exhibit a range of different aerosol characteristics.

2. Data and Methodology

2.1. Global Correction for Absorbing Aerosols

[4] This aerosol climatology is based on monthly statistics by ground-based sun-photometry (AERONET [*Holben et al.*, 1998]), imposed on a globally complete and consistent modelled background (AeroCom model median [*Kinne et al.*, 2006]). For this task AERONET local statistics of τ_{aer}, ω and Ångström parameter were gridded at 1x1 degree spatial resolution with site-specific assigned scores for data-quality and regional representation (T. Eck, personal communication, 2008). Hereby sites with better regional repre-

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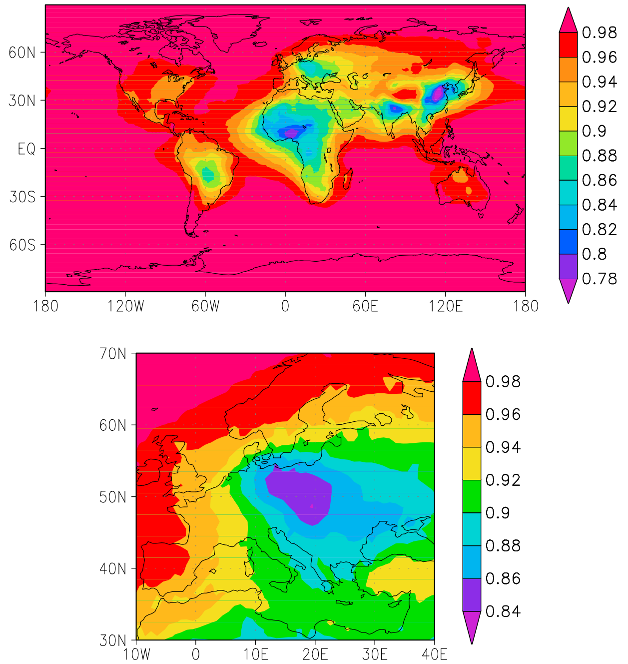

Figure 1. Mean correction factor for absorbing aerosols at 315 nm: (top) for a global map and (bottom) for Europe.

sentation were allowed to influence increasing layers of adjacent grids.

[5] The necessary extrapolation from the visible to UV wavelengths is based on particle size (via the Ångström parameter) and the assumption that dust (here solely attributed to the coarse sizes) is more absorbing in the UV [*Kinne*, 2009]. If the local ω is smaller than the suggested coarse mode contribution, then the excess absorption has been assumed to be caused by accumulation mode aerosol. The refractive indices are assumed and during this process also the effective radii of modes are constrained. Finally, ω is determined by applying mixing rule for coarse and accumulation mode properties.

[6] In this work, we used this global monthly aerosol climatology for τ_{abs} [$\tau_{abs} = \tau_{aer}*(1 - \omega)$] at 315 nm and applied the parameterization suggested by *Krotkov et al.* [2005].

$$Ca = \frac{1}{1 + K * \tau_{abs}}, \quad (1)$$

where *Ca* is the post-correction factor to multiply the OMI UV estimate, to account for absorbing aerosols. The part $1 + K * \tau_{abs}$ of this equation describes the linear dependence of the overestimation ratio of satellite-based UV on τ_{abs}. Previous studies [*Arola et al.*, 2005; *Krotkov et al.*, 2005] have determined that the slope *K* weakly depends on solar zenith angle (SZA) and aerosol type. Neglecting these dependences and using an average value of $K = 3$ in equation 1 for all SZAs and aerosol types will introduce an error that is proportional to τ_{abs}. For typical $\tau_{abs} < 0.1$ and SZA < 60 degrees the Ca error is less than 5%.

[7] We applied equation 1 with $K = 3$ and the monthly climatology at 315 nm for both 305 and 324 nm OMI irradiances, thus not taking into account the spectral dependence of τ_{abs} within 10 nm. Assuming τ_{aer} of 0.7, Ångström parameter of 1.2 and ω of 0.95 at 315 nm, this would lead to under- and overestimation of less than 0.3% in the correction factor at 305 and 324 nm, respectively.

[8] Figure 1 shows an example of this global correction factor at 315 nm as an annual mean over all months. For instance, the strongest reduction of surface UV irradiance, due to the absorbing aerosols, is about 22% in Equatorial West Africa and East Asia, about 15% in Eastern Europe and 5–10% on the East Coast of the United States.

2.2. Ground-Based Data

[9] We selected eight European stations that provide spectral surface UV measurements, to evaluate the improvements that can be obtained in OMI UV by applying this correction. The ground-based spectral irradiance data were corrected for possible wavelength shifts and standardized to 0.55 nm spectral resolution (the same as for OMI spectral UV data) using the SHICrivm algorithm [*Slaper et al.*, 1995]. Some information about the ground-based sites and references for further details are given in Table 1.

[10] All the instruments included in our study (in Table 1) were inter-compared with the travelling standard QASUME spectroradiometer [*Gröbner et al.*, 2006] maintained at the PMOD/WRC (Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center see http://www.pmodwrc.ch/euvc/euvc.html). Results showed differences from −3% to +7% which could influence the average statistics presented here when comparing ground-based and OMI UV measurements.

3. Results

[11] We compared both 305 and 324 nm irradiances from the OMI UV product (I_S) against ground-based measurements (I_G). Since very similar improvements in reduced relative overestimation were reached at these wavelengths by the correction for absorbing aerosols, below we show the

Table 1. Stations Used in the Validation Study

Location	Lat (°N)	Lon (°N)	Alt [m]	Instrument	Reference
El Arenosillo, Spain	37.1	6.7	10	Brewer MKIII	
Hradec Kralove, Czech Republic	50.1	15.8	285	Brewer MKIV	
Jokioinen, Finland	60.8	23.4	104	Brewer MKIII	[*Lakkala et al.*, 2008]
Lampedusa, Italy	35.5	12.6	50	Brewer MKIII	[*di Sarra et al.*, 2008]
Reading, UK	51.2	−0.9	66	Bentham	[*Gröbner et al.*, 2006]
Rome, Italy	41.9	12.5	75	Brewer MKIV	[*Ialongo et al.*, 2008]
Thessaloniki, Greece	40.6	22.9	60	Brewer MKIII	[*Garane et al.*, 2006]
Villeneuve d'Ascq, France	50.7	3.0	60	Jobin Yvon	[*Buchard et al.*, 2008]

Table 2. Statistics of the Ratio ($\frac{I_S}{I_G}$) at 324 nm for the Validation Sites[a]

	$Mean_{clear}$	Std_{clear}	N_{clear}	$Mean_{all}$	Std_{all}	N_{all}
El Arenosillo	1.17 (1.22)	0.135 (0.140)	125	1.17 (1.22)	0.203 (0.213)	258
Hradec Kralove	1.14 (1.36)	0.128 (0.114)	39	1.17 (1.37)	0.423 (0.494)	184
Jokioinen	1.07 (1.17)	0.121 (0.128)	51	1.04 (1.12)	0.361 (0.395)	286
Lampedusa	1.05 (1.16)	0.133 (0.144)	80	1.07 (1.17)	0.332 (0.358)	133
Reading	1.28 (1.34)	0.121 (0.109)	63	1.32 (1.39)	0.337 (0.355)	395
Rome	1.21 (1.32)	0.143 (0.138)	89	1.23 (1.35)	0.308 (0.329)	185
Thessaloniki	1.11 (1.23)	0.114 (0.097)	93	1.16 (1.28)	0.351 (0.383)	255
Villeneuve d'Ascq	1.12 (1.19)	0.086 (0.073)	40	1.14 (1.21)	0.249 (0.272)	221

[a]Results from the both operational OMI and post-corrected OMI for absorbing aerosols are shown, the former statistics being in the parentheses. Results for both clear-sky ("clear") and all-sky ("all") cases are included. N is the number of measurements in each data set.

results at 324 nm only. We included data from full years of 2005 and 2006. Ground-based data were averaged within a one-hour time window centered around the OMI overpass time, resulting in typically from one to three spectra included in this average. Moreover, comparisons were done separately for clear-sky and all-sky data sets. Clear-sky data were determined based on OMI cloud modification factor (CMF = $I_{Scloudy}/I_{Sclear}$), including cases of CMF larger than 0.95.

[12] We calculated the validation statistics between satellite-derived and ground-based data for the irradiance ratios (I_S/I_G). This ratio may become unstable at very low intensities, therefore we excluded cases when both of the following conditions were met: the irradiance from ground-based instrument at 324 nm was below 50 $mW/m^2/nm$ and at the same time the irradiance from OMI UV was more than four times higher. These cases are likely due to either rapidly changing cloudiness or occasional technical problems in the ground-based instrument. However, only few cases were excluded by this requirement: two (out of a total of 586) and seven (out of a total of 2105) for clear-sky and all-sky data sets, respectively.

[13] Table 2 shows the statistics of the 324 nm comparisons for the clear-sky and all-sky data sets when the correction was applied. The corresponding parameter for currently operational OMI UV follows in parentheses. The variability of I_S/I_G is slightly decreased at all the sites for the larger all-sky data set. The correction applied for absorbing aerosols decreases the overestimation by 5% to 20% depending on the station. Correlation coefficients (not shown) were high (for all the sites larger than 0.95, except for the values of around 0.92 in Lampedusa) and they were unchanged if the absorbing aerosol correction was applied.

[14] We also considered three-month seasons (December–February, DJF; March–May, MAM; June–August, JJA; and September–November, SON) separately to assess how the use of aerosol climatology captures the seasonal variability. Table 3 shows the mean ratio ($\frac{I_S}{I_G}$) at 324 nm with and without correction for the clear-sky cases during these different seasons. Moreover, seasonally averaged values of τ_{aer} and ω at 315 nm from the monthly aerosol climatology are given. In all of the sites, the bias is most reduced in the summer season, while this reduction is more modest in winter and fall. Comparisons of τ_{aer} and ω from climatology against AERONET measurements in El Arenosillo, Rome and Villeneuve d'Ascq (not shown) suggest that the climatology represents much stronger seasonality in τ_{aer} with low values in winter and fall. Therefore, it is evident that the aerosol correction is too small in winter and fall (and to some extent during spring), while it performs better in the summer. This seasonality is also one significant reason why the results of Table 2 show such a high remaining overestimation. There are also other possible reasons, for instance the seasonality in some sites suggests that the cosine error in ground-based data is not fully corrected for increasing SZA. The other ground-based instrument related uncertainties, assessed when comparing against the travelling standard QASUME spectroradiometer [*Gröbner et al.*, 2006],

Table 3. Mean of the Ratio ($\frac{I_S}{I_G}$) at 324 nm for Different Seasons[a]

	DJF	MAM	JJA	SON
El Arenosillo	1.19 (1.21)	1.18 (1.22)	1.14 (1.22)	1.18 (1.23)
	0.20/0.96	0.32/0.96	0.47/0.94	0.24/0.95
Hradec Kralove	1.26 (1.40)	1.10 (1.33)	1.01 (1.26)	1.15 (1.39)
	0.48/0.92	0.89/0.93	1.10/0.93	0.76/0.92
Jokioinen	- (-)	1.11 (1.22)	1.04 (1.14)	1.09 (1.16)
	0.27/0.97	0.48/0.95	0.65/0.95	0.43/0.95
Lampedusa	1.07 (1.12)	1.06 (1.20)	1.03 (1.17)	1.04 (1.12)
	0.29/0.95	0.66/0.94	0.68/0.93	0.50/0.94
Reading	1.36 (1.39)	1.24 (1.32)	1.18 (1.27)	1.34 (1.38)
	0.27/0.97	0.54/0.96	0.60/0.96	0.31/0.96
Rome	1.32 (1.40)	1.11 (1.23)	1.09 (1.23)	1.23 (1.34)
	0.31/0.94	0.62/0.94	0.57/0.92	0.57/0.94
Thessaloniki	1.20 (1.27)	1.06 (1.19)	1.02 (1.20)	1.09 (1.21)
	0.36/0.94	0.68/0.94	0.80/0.93	0.59/0.94
Villeneuve d'Ascq	1.18 (1.23)	1.13 (1.23)	1.02 (1.12)	1.11 (1.17)
	0.32/0.96	0.64/0.95	0.65/0.95	0.40/0.96

[a]DJF, December-January-February; MAM, March-April-May; JJA, June-July-August; and SON, September-October-November. Clear-sky cases from the both operational OMI and post-corrected OMI for absorbing aerosols are shown, the former statistics being in the parentheses. In the second line for each site, seasonally averaged values of τ_{aer}/ω at 315 nm are given.

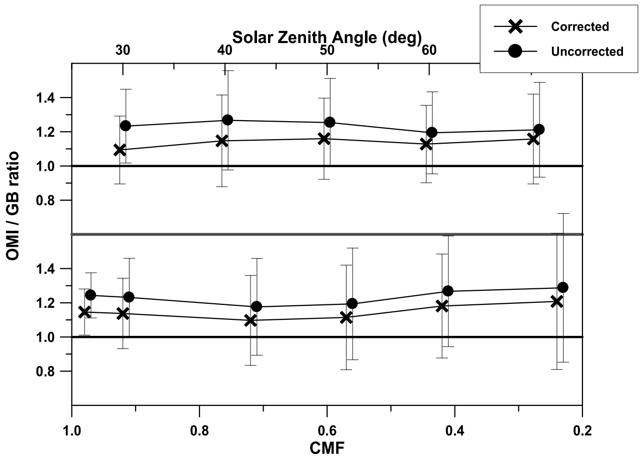

Figure 2. Mean ratio of satellite-based and ground-based spectral irradiance at 324 nm ($I_{S_{324nm}}/I_{G_{324nm}}$) against both SZA and CMF, for uncorrected and corrected OMI data.

have an influence on the statistics presented here too. Also, enhanced gas absorption (mainly by NO_2) has a similar effect to aerosol absorption, but is not included in the correction. However, this effect is likely to be relatively small at many of these validation sites. Of the sites in our study, Rome and Thessaloniki are probably most influenced by this effect. Moreover, based on these results, we would argue that part of the remaining overestimation is due to the enhanced UV absorption by organic aerosols [e.g., *Corr et al.*, 2009; *Martins et al.*, 2009] that is not represented in the climatology extrapolated from AERONET measurements at the visible wavelengths.

[15] Figure 2 shows I_S/I_G averaged over bins of SZA and OMI cloud modification factor for uncorrected and corrected OMI UV data. It can be seen that there is no obvious SZA dependent error in the overall OMI data. However, as was discussed above, some individual sites exhibit this kind of pattern, likely due to the cosine error left in the ground-based data. Similarly, the bias is independent of CMF to large extent. However, in the comparisons we wanted to separate the clear-sky cases to concentrate on the effect of absorbing aerosols.

4. Conclusions

[16] Overestimation in satellite-based UV data, when compared to the ground-based UV measurements, have been documented in several studies. It is believed that this is mostly caused by the absorbing aerosols that have not been accounted for in satellite-UV algorithms so far. While the problem is recognized, a proper correction for this effect on a global scale has not been applied before. Recently a novel global climatology of aerosol optical properties has become available [*Kinne*, 2009]. In this work, we used this global monthly aerosol climatology and applied the parameterization suggested by *Krotkov et al.* [2005] to correct for absorbing aerosols in the OMI UV product. We then evaluated the improvements in OMI UV that can be achieved by incorporating the correction for absorbing aerosols by comparing spectral OMI UV products with synchronous ground-based measurements from various European UV monitoring sites with different aerosol characteristics.

[17] In general, results showed a significantly reduced overestimation of 5–20%, a lower variability, and an unchanged, high correlation coefficient. We now plan to implement this correction into the next version of OMI UV data. However, it should also be stressed that AERONET has a better coverage in Europe than in some other areas. Also, some aerosol types (e.g. biomass burning) do not have a very significant role in the aerosol climatology of Europe, while they have a great significance in some geographical regions. Therefore validation studies, focusing on other geographical areas, will be an important topic of future research.

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